The NPDGamma Experiment

Hadronic Parity Violation in the Capture of Cold Neutrons on Protons

$$\vec{n} + p \rightarrow d + \gamma_{(asym)}$$

CAP Congress 2014

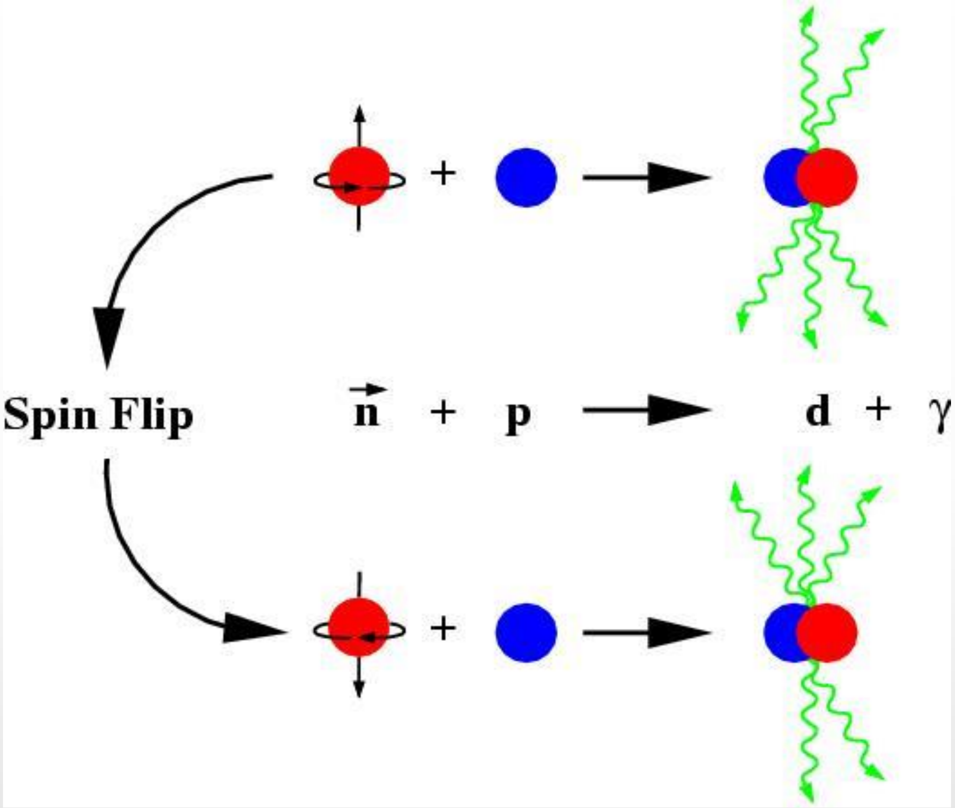
Michael Gericke (University of Manitoba)

For the NPDGamma Collaboration

~50 Collaborators from ~20 institutions

The NPDGamma Experiment

Polarized Cold Neutrons on Liquid Hyrdogen:



Has a small "predicted" asymmetry: $A_\gamma \simeq -5 \times 10^{-8}$ … there should be one …

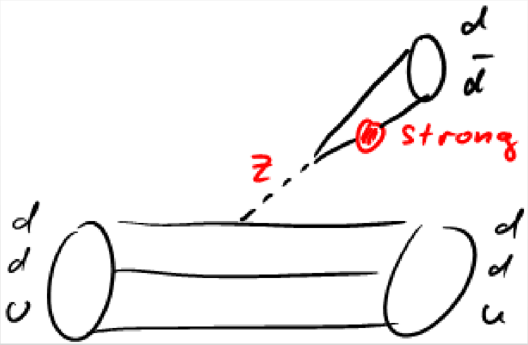
The NPDGamma Experiment

… because

$$J_N^W = \bar{\psi}_u \gamma^\mu \left(1 - \frac{8}{3}\sin^2\theta_W - \gamma_5\right)\psi_u - \bar{\psi}_d \gamma^\mu \left(1 - \frac{4}{3}\sin^2\theta_W - \gamma_5\right)\psi_d$$

If it is really small or zero, there should be a reason!

Well … yes, it's interference with the strong interaction (of course)!



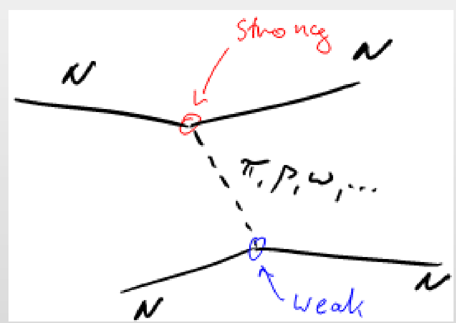
The NPDGamma Experiment

The problem is:

We don't understand strong dynamics at low energy!

$$J_N^W = \bar{\psi}_u \gamma^\mu \left(1 - \frac{8}{3}\sin^2\theta_W - \gamma_5\right)\psi_u - \bar{\psi}_d \gamma^\mu \left(1 - \frac{4}{3}\sin^2\theta_W - \gamma_5\right)\psi_d$$

$$\mathcal{L}_{QCD} = \bar{\psi}_q \left(i\gamma^\mu D_\mu - m_q\right)\psi_q - \frac{1}{2}Tr\left(G_{\mu\nu}G^{\mu\nu}\right)$$

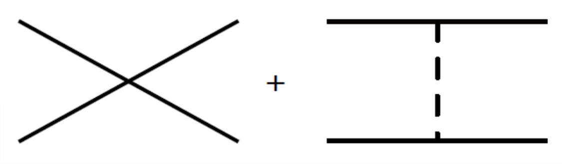


The NPDGamma Experiment

… experimental constraints on A_γ provide a benchmark for low E QCD models

Chiral Perturbation Theory for $A \geq 2$:

- Leading order: contact + one-pion exchange



- Relevant for NPDGamma:

All possible P violating and CP conserving current-current contact terms with isospin change $\Delta I=1$:

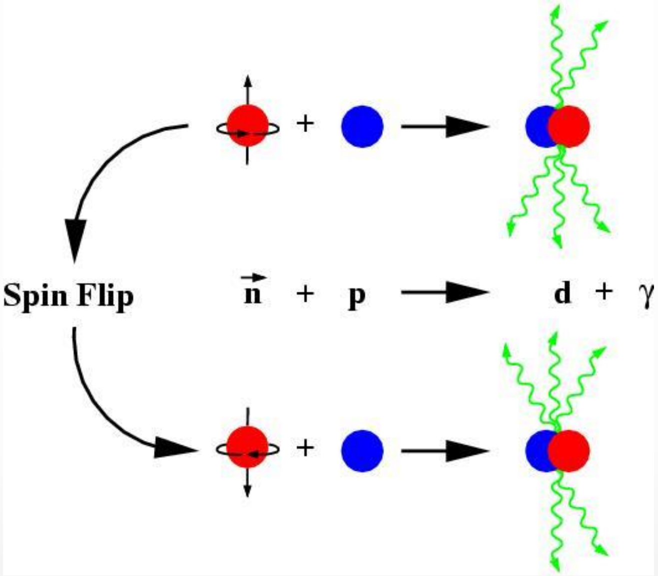
$$O_2 = \frac{g_2}{\Lambda_\chi^2}\bar{\psi}_N 1\gamma_\mu\psi_N\bar{\psi}_N\tau_3\gamma^\mu\gamma_5\psi_N \qquad O_6 = \frac{g_6}{\Lambda_\chi^2} i\varepsilon^{ab3}\bar{\psi}_N\tau_a\gamma_\mu\psi_N\bar{\psi}_N\tau_b\gamma^\mu\gamma_5\psi_N$$

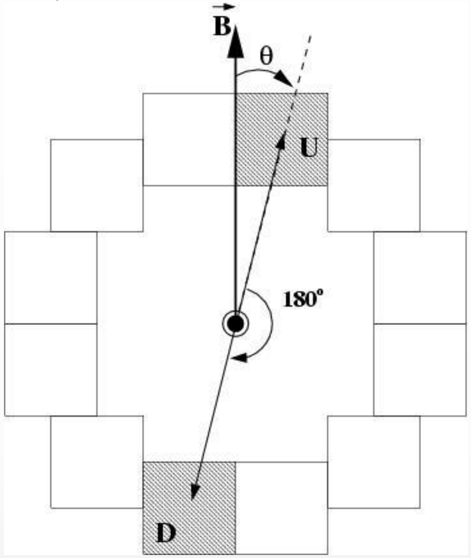
$$O_4 = \frac{g_4}{\Lambda_\chi^2}\bar{\psi}_N\tau_3\gamma_\mu\psi_N\bar{\psi}_N 1\gamma^\mu\gamma_5\psi_N \qquad \tilde{O}_6 = \frac{\tilde{g}_6}{\Lambda_\chi^3} i\varepsilon^{ab3}\bar{\psi}_N\tau_a\sigma_{\mu\nu}q^\nu\psi_N\bar{\psi}_N\tau_b\gamma^\mu\gamma_5\psi_N$$

$$\boxed{A_\gamma \propto \frac{\Lambda_\chi}{2M_N}\left(\frac{g_2}{2} - \frac{g_4}{4} - g_6\right) + \tilde{g}_6 = -0.107 h_\pi^{\Delta I=1}}$$

The NPDGamma Observable

The main NPDGamma observable is the up-down asymmetry in the angular distribution of gamma rays with respect to the neutron spin direction:





$$\frac{d\sigma}{d\Omega} \propto \frac{1}{4\pi}\left(1 + A_\gamma \cos\theta\right)$$

$$A_{raw} = \left(P_n F_n D_n G\right) A_\gamma \cos\theta = \frac{1}{2}\left(\frac{\sigma_U^\uparrow - \sigma_D^\uparrow}{\sigma_U^\uparrow + \sigma_D^\uparrow} + \frac{\sigma_U^\downarrow - \sigma_D^\downarrow}{\sigma_U^\downarrow + \sigma_D^\downarrow}\right)$$

The NPDGamma Observable

The observed cross-section is the result of an electro-magnetic transition between initial and final two nucleon states.

The possible amplitudes include both parity even M1 and parity odd E1 transitions from L=1 states as a result of the weak perturbation.

$$\frac{d\sigma}{d\Omega} \propto \left| \langle \psi_f | \mathbf{E1} | \psi_i \rangle + \langle \psi_f | \mathbf{M1} | \psi_i \rangle \right|^2$$

$$\mathbf{H} = \mathbf{H_s} + \mathbf{V_{PNC}} \qquad a = \frac{\langle \psi_{\ell=1} | \mathbf{V_{PNC}} | \psi_{\ell=0} \rangle}{\Delta E} \qquad |\psi_{i,f}\rangle = |\psi_{i,f,\ell=0}\rangle + a|\psi_{i,f,\ell=1}\rangle$$

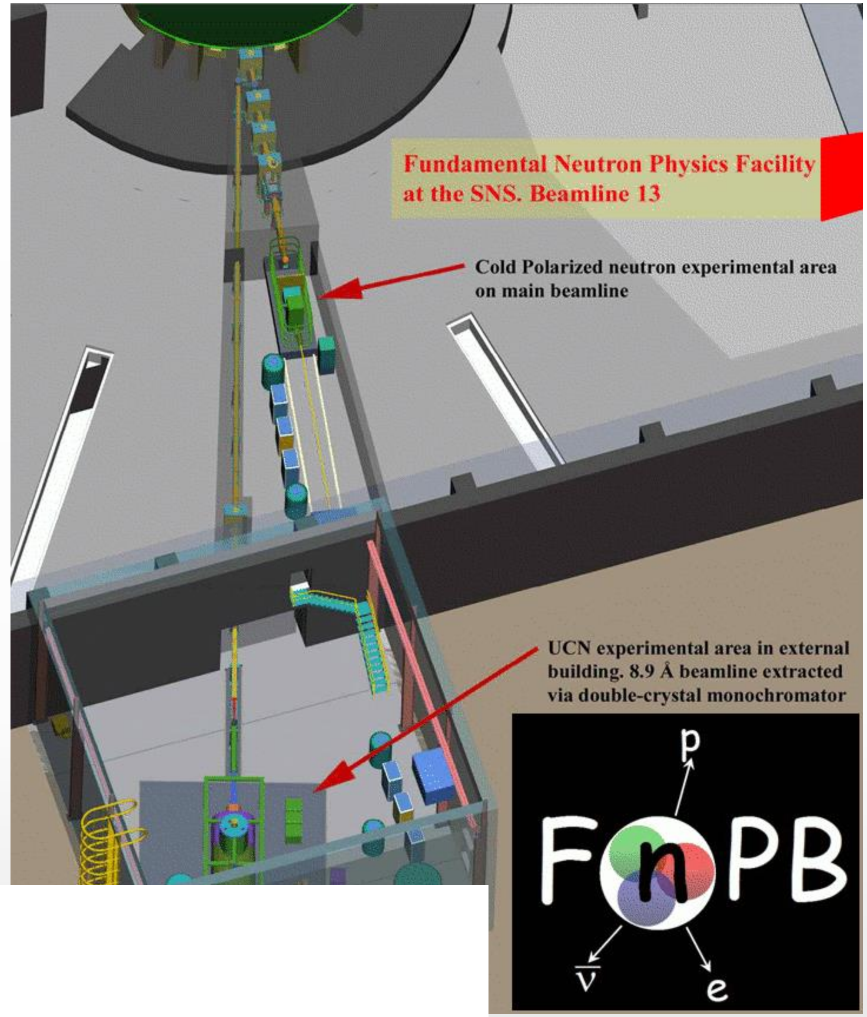
$$A_\gamma = -0.107 h_\pi^{\Delta I=1} \simeq -5 \times 10^{-8}$$

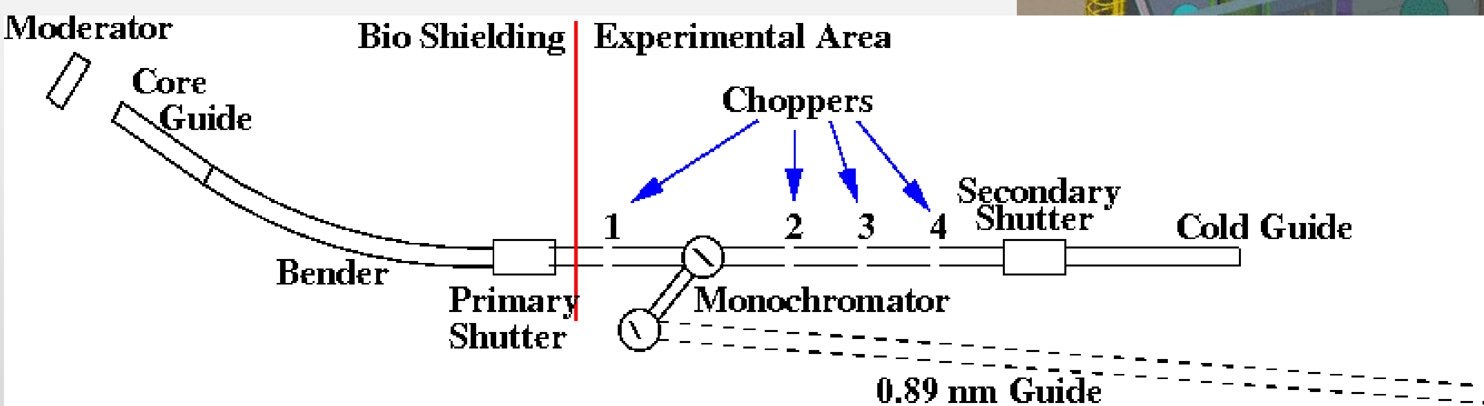
NPDGamma proposes to measure the asymmetry to 1×10^{-8} stat. + sys.

Spallation Neutron Source (SNS)

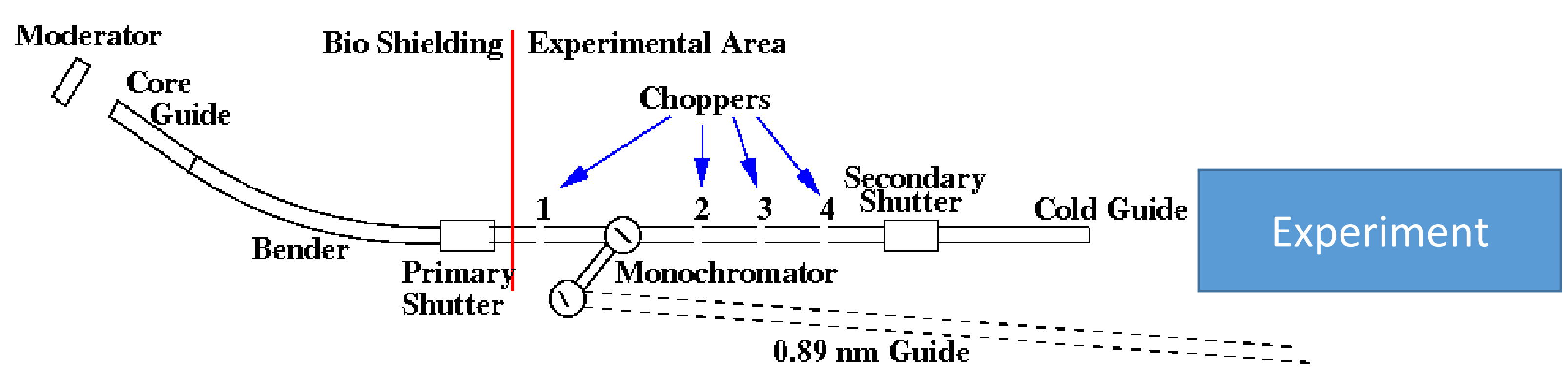
The Fundamental Neutron Physics Beam (FnPB)

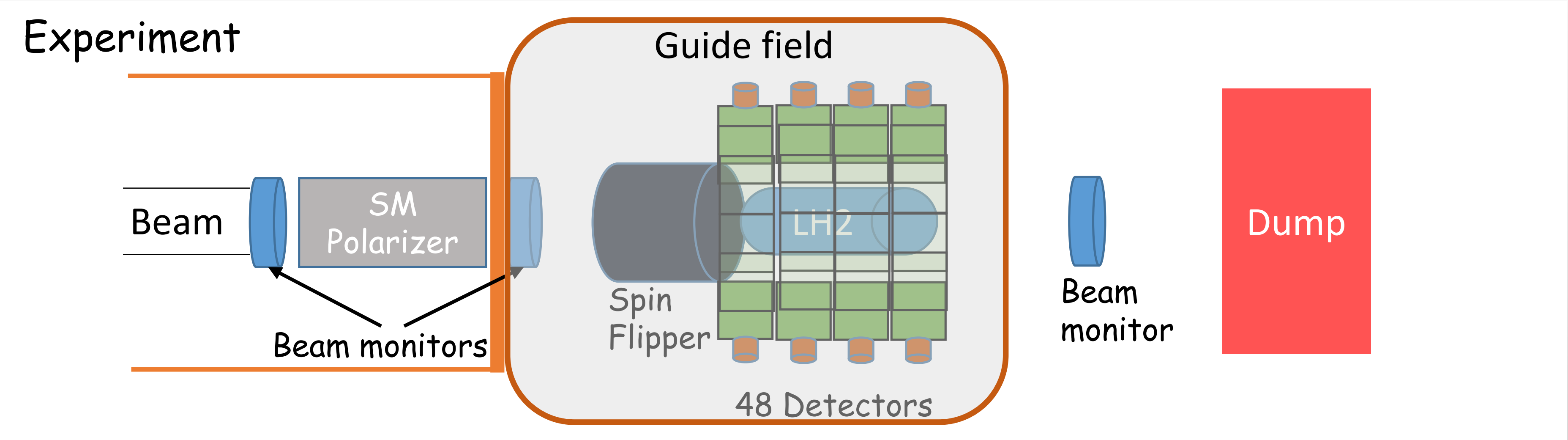
- LH2 moderator
- 17 m long guide ~ 20 m to experiment
- one polyenergetic cold beam line
- ~ 40 m to nEDM UCN source
- 4 frame overlap choppers
- 60 Hz pulse repetition





NPDGamma Layout





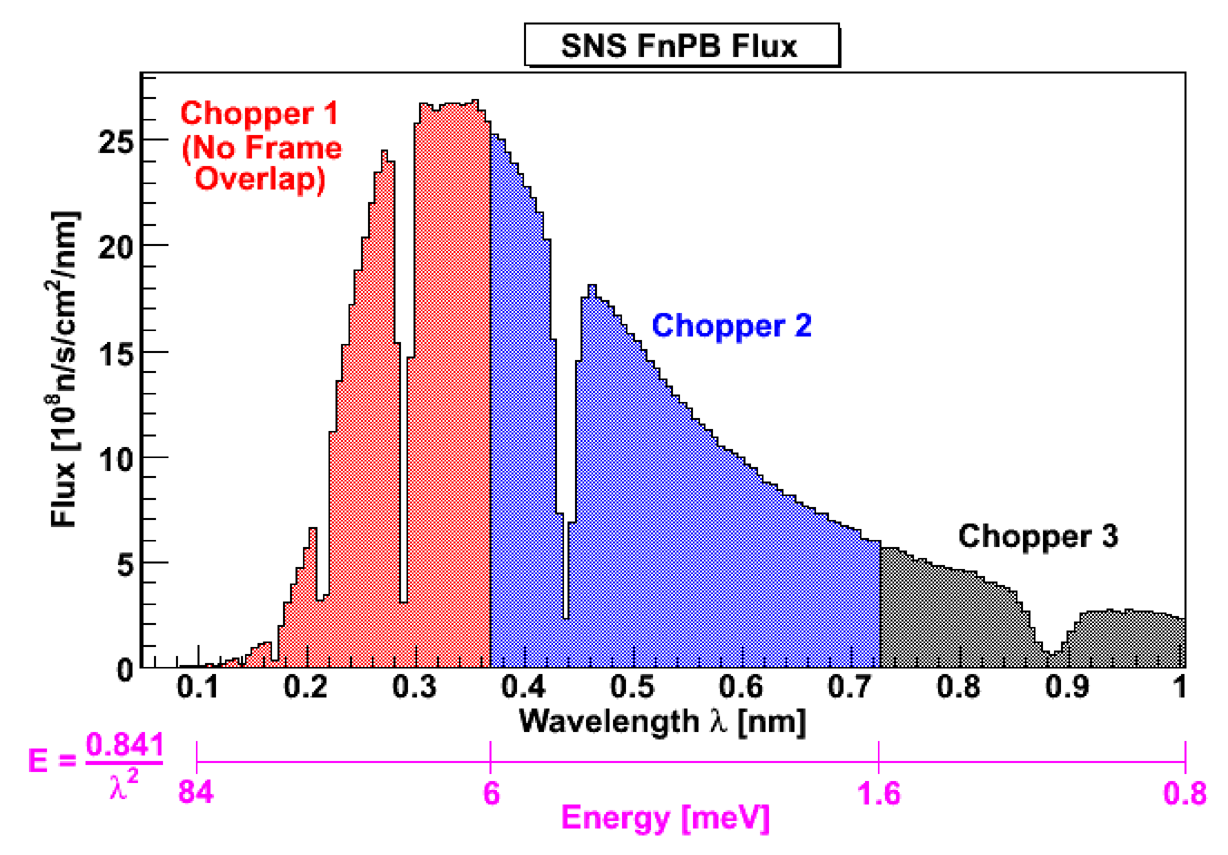
NPDGamma Layout

Moder

Exp

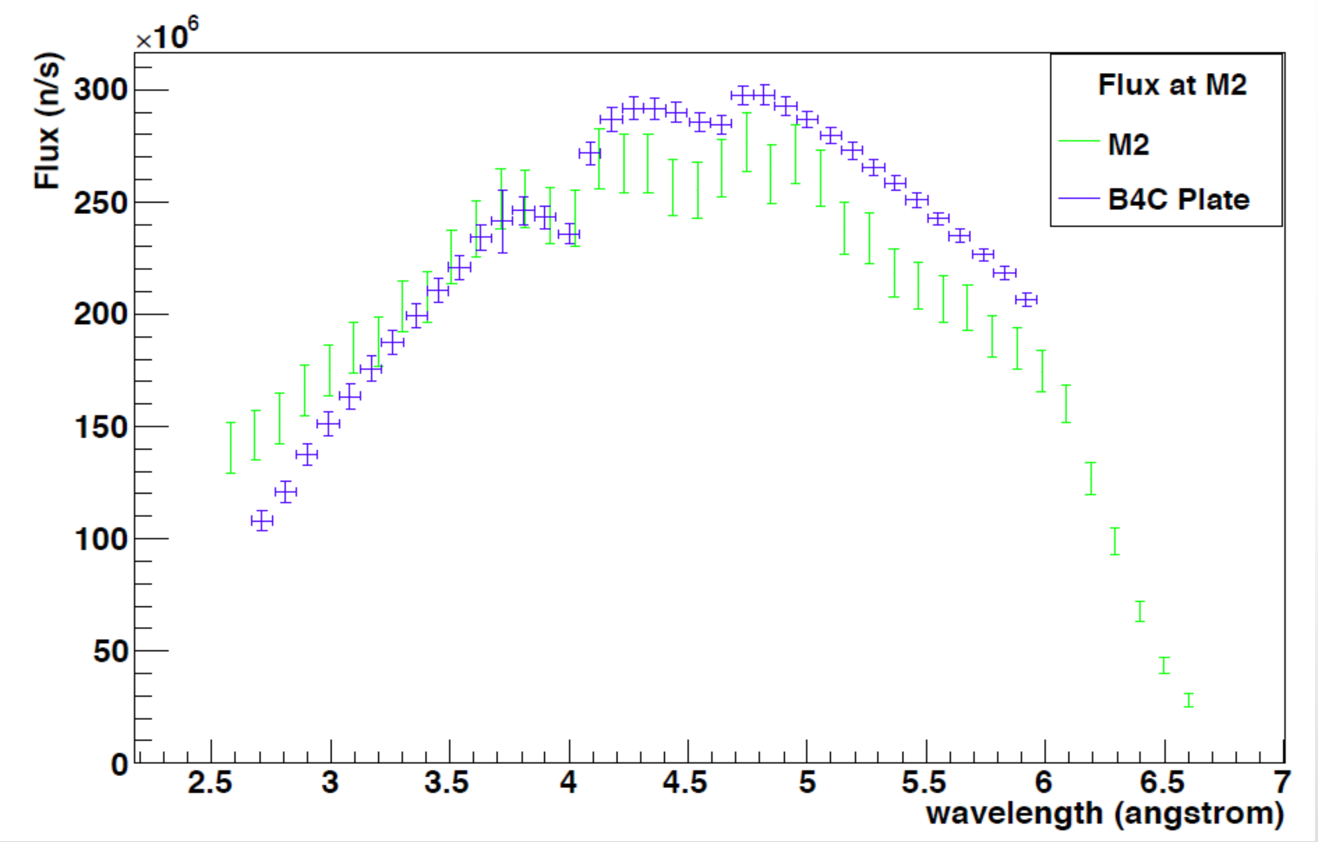
SNS Beam Properties

Choppers allow for neutron energy selection (a big plus for spallation sources when it comes to systematic effect control)



SNS Beam Properties

Choppers allow for neutron energy selection (a big plus for spallation sources when it comes to systematic effect control)

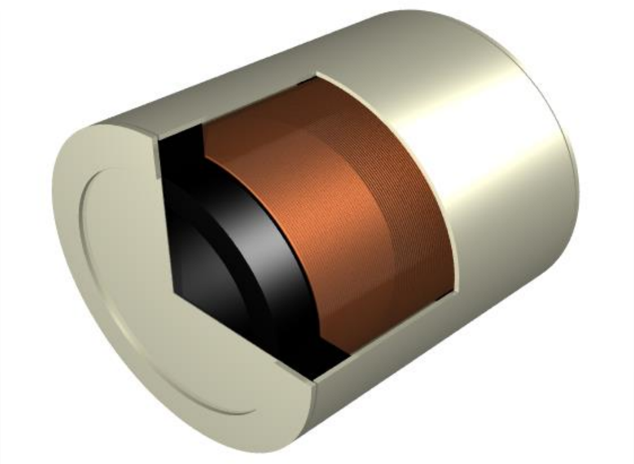


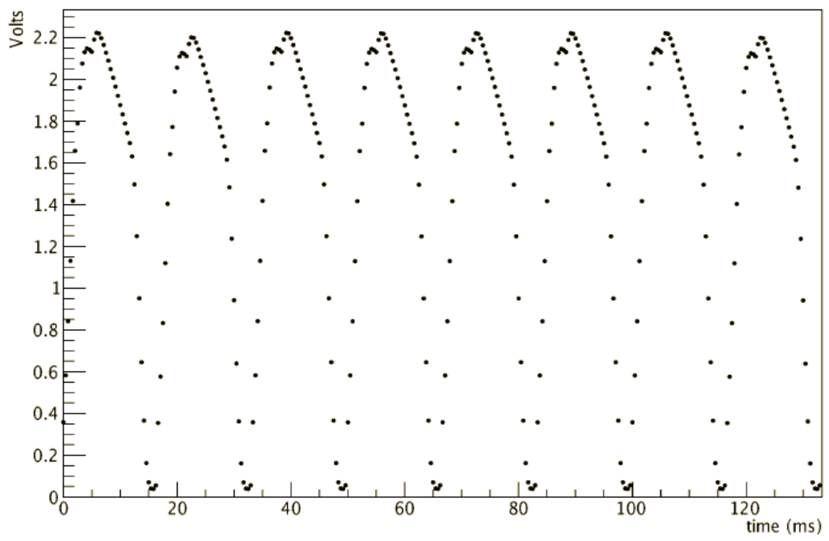
Beam Monitor Signal (Mark McCrea)

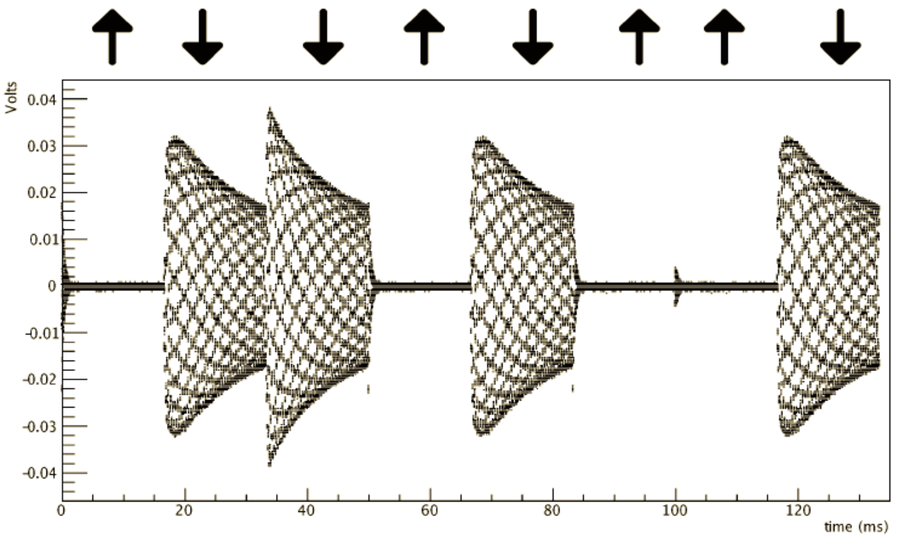
NPDGamma Components

Radio Frequency Resonant Spin flipper:

- Pulse-by-pulse neutron spin flipping
- Ramped field to take account of n TOF
- Eight-step sequence to cancel drifts



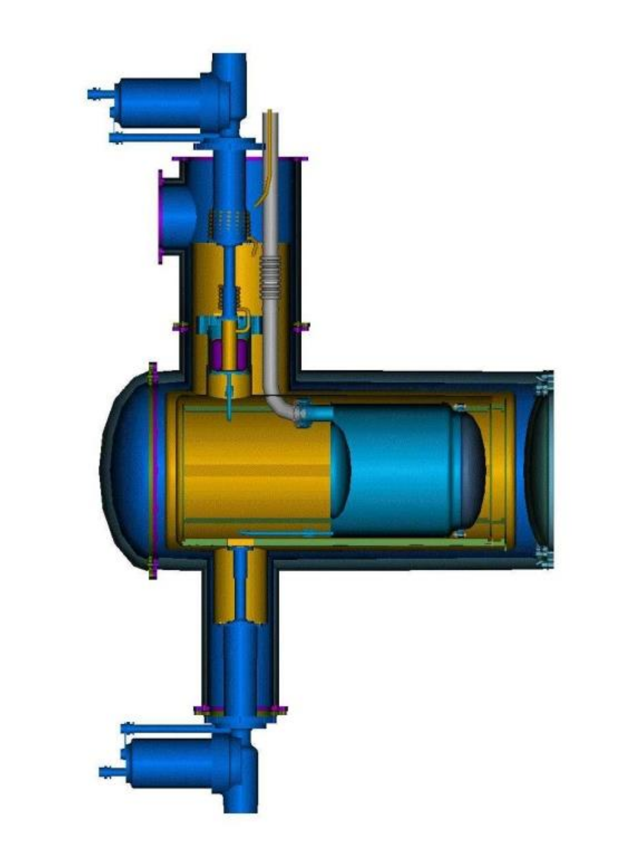


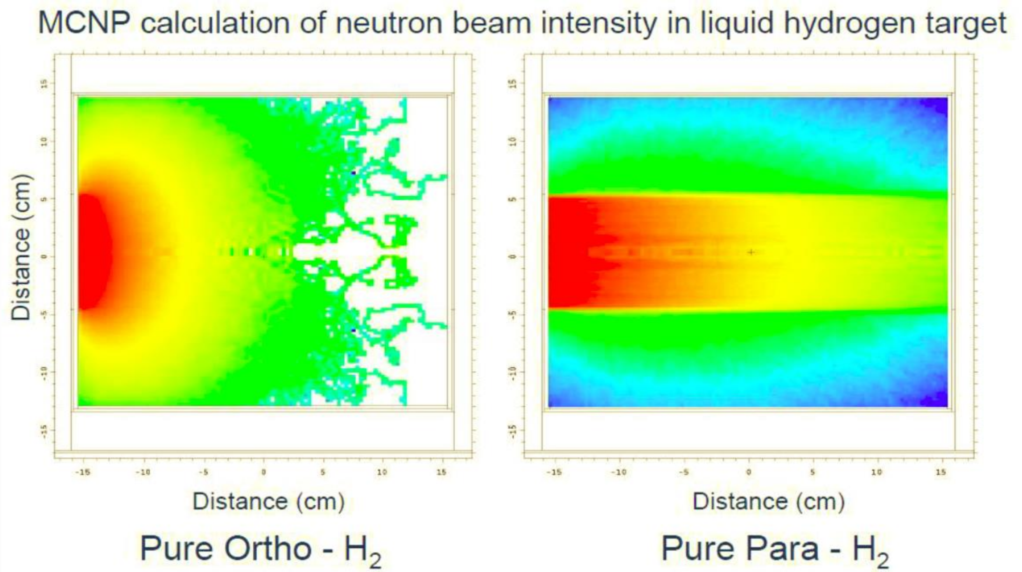


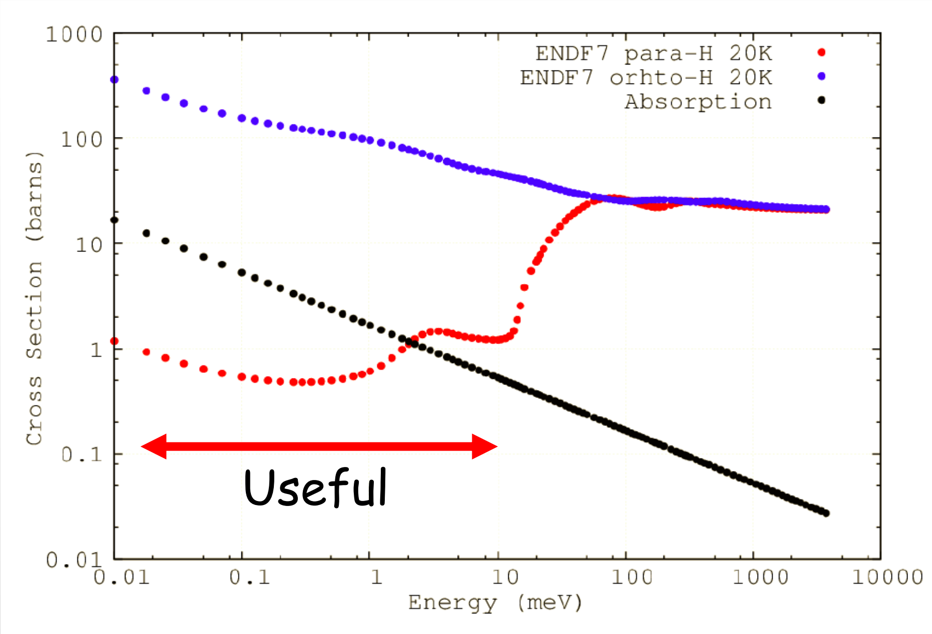
NPDGamma Components

Liquid Hydrogen Target:

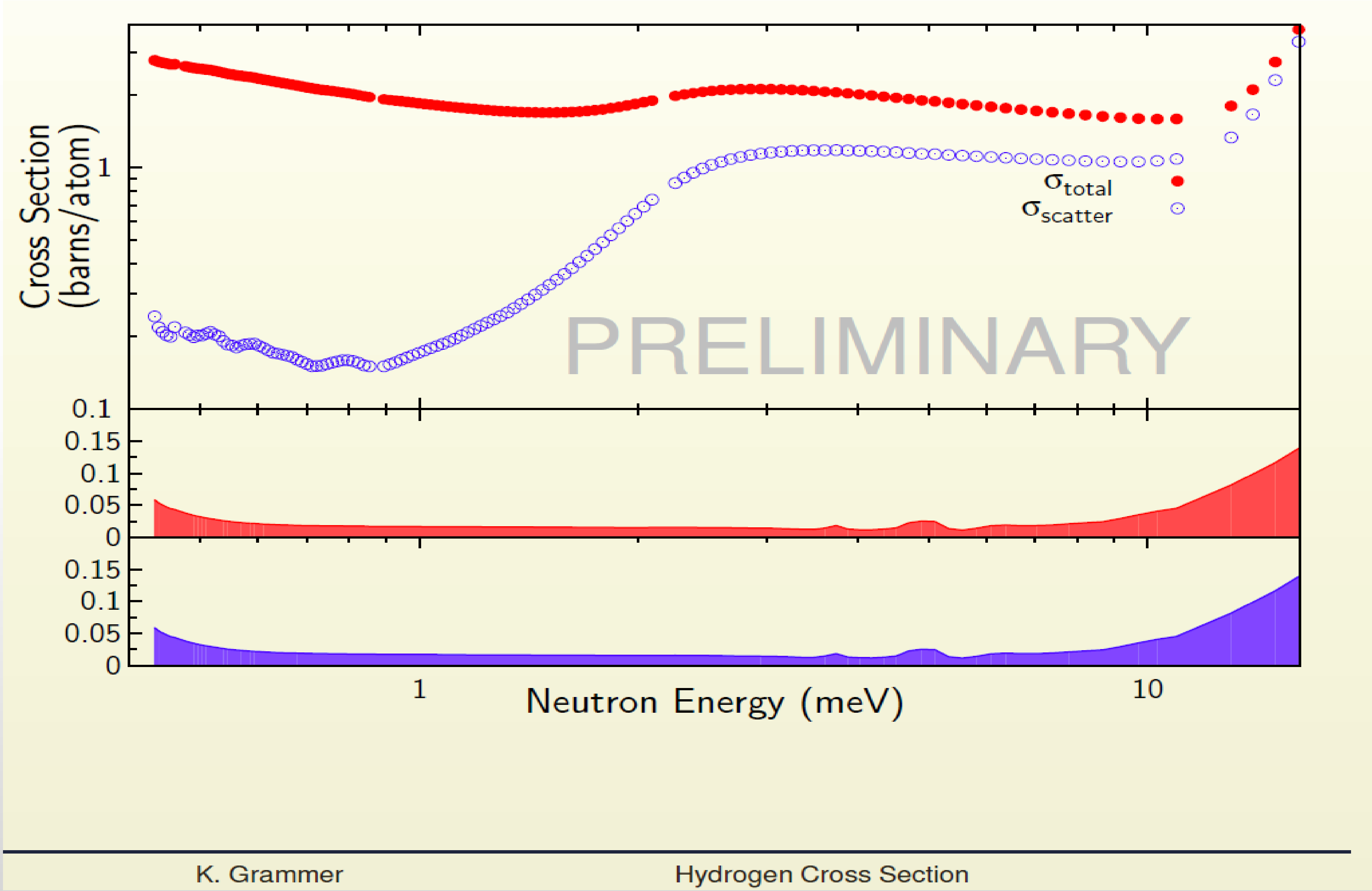
- 20 liter Para-Hydrogen



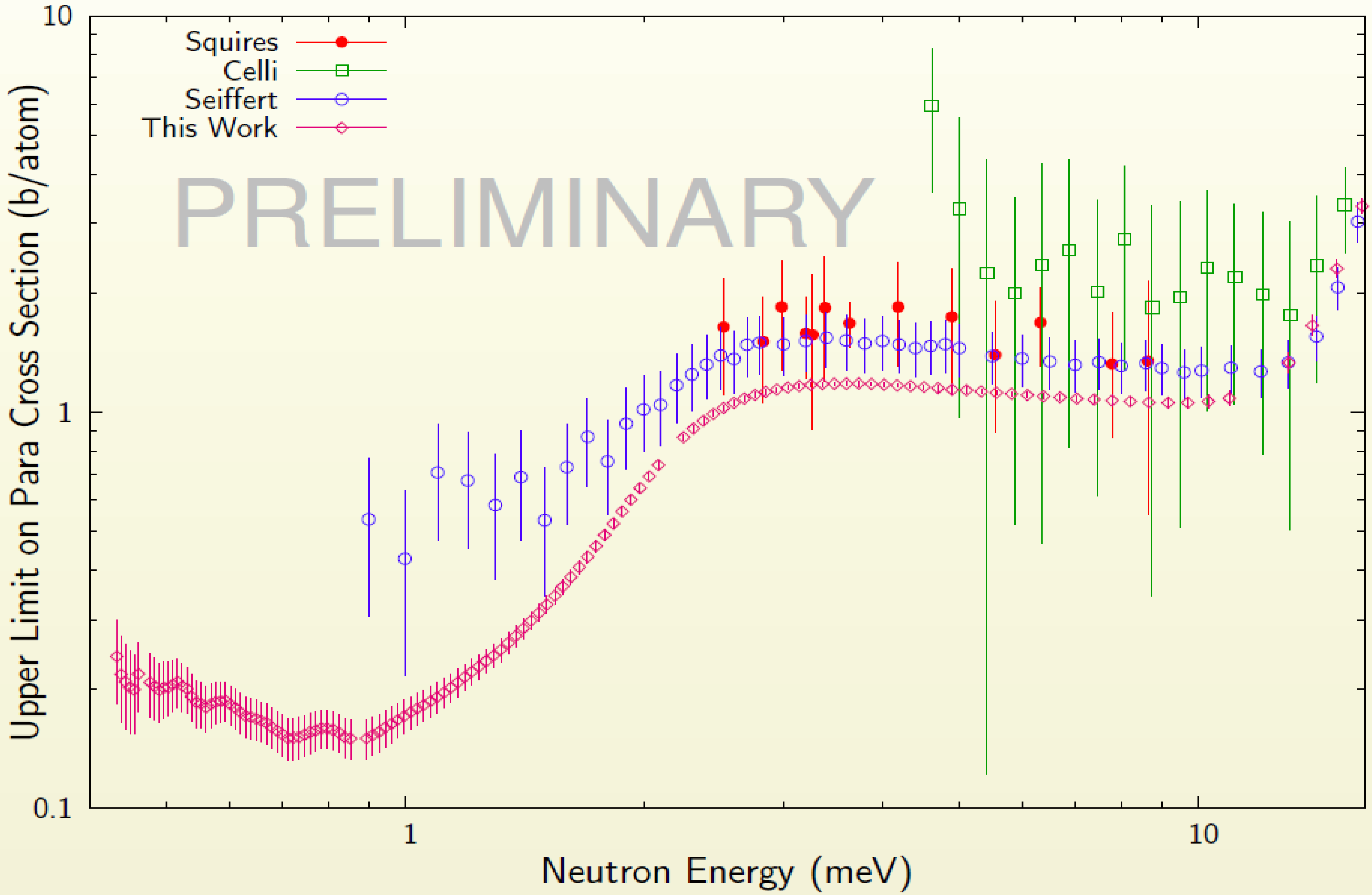




NPDGamma also made the most precise measurement of the total hydrogen scattering cross-section (1%) … to be published soon … Work by Kyle Grammar, U. of Tennessee



NPDGamma also made the most precise measurement of the total hydrogen scattering cross-section (1%) … to be published soon … Work by Kyle Grammar, U. of Tennessee



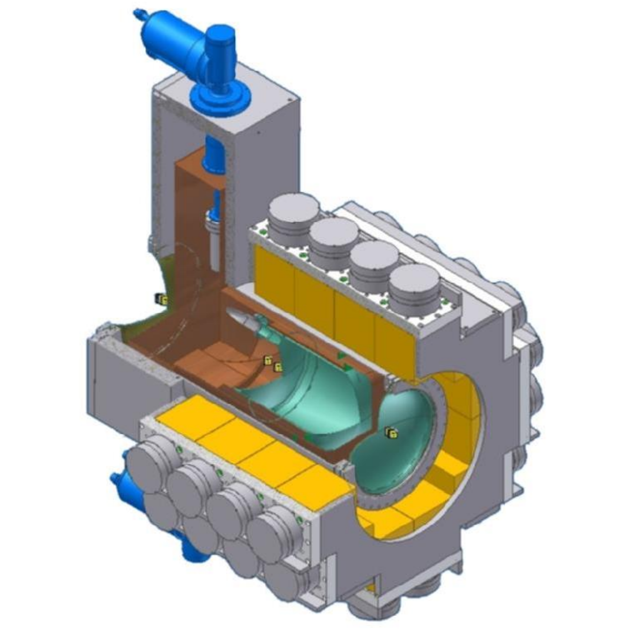
G.L. Squires and A.T. Stewart. Proc. R. Soc. A Math. Phys. Eng. Sci., 1955.
W.D. Seiffert, B. Weckermann, und R. Misenta, Z. Naturforsch. A, 1970.
M. Celli, N. Rhodes, A. K. Soper, and M. Zoppi. J. Phys. Condens. Matter, 1999.

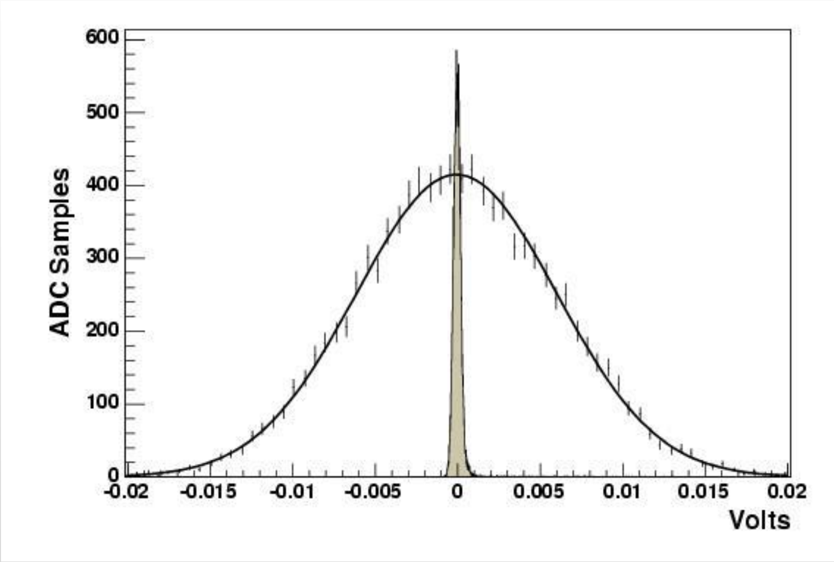
K. Grammer Hydrogen Cross Section

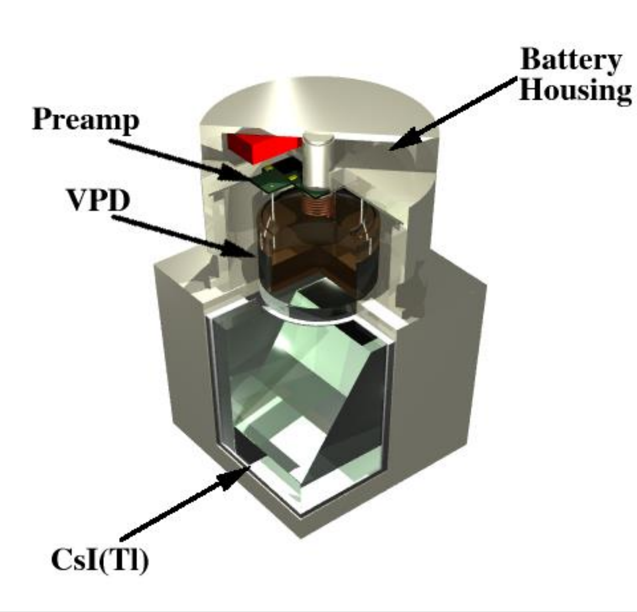
NPDGamma Components

Detectors:

- $\Delta\Omega = 3\pi$
- 48 Cs(Tl) scintillators operated in current mode
- Coupled to 3 inch vacuum photodiodes
- Signal processed via high gain, low noise, trans-impedance amplifier (I-V) and sampled by 12 bit ADCs





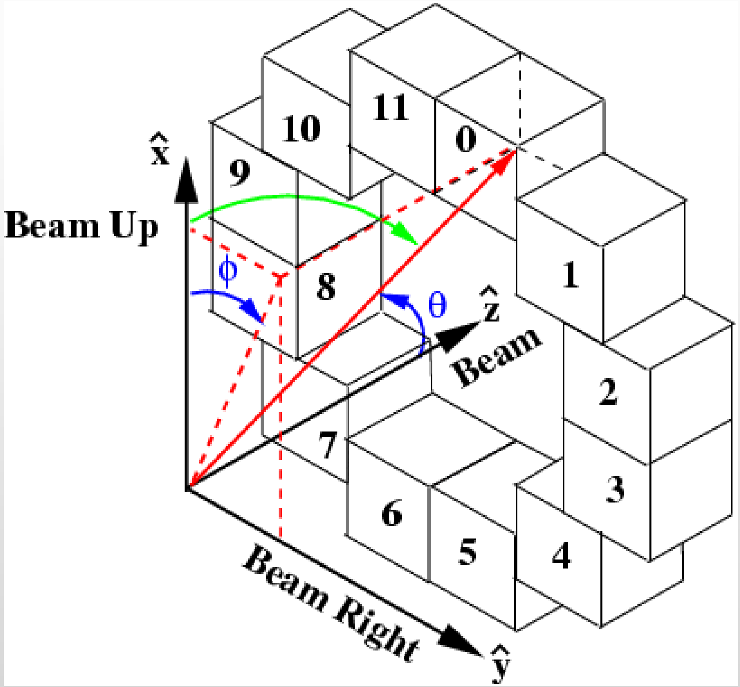


Data Analysis Procedure

Measured Spin Sequence Asymmetries :

$$A^d_{msr} = \frac{1}{2}\sum_{\uparrow}\left(\frac{Y^d_{\uparrow} - Y^{d+6}_{\uparrow}}{Y^d_{\uparrow} + Y^{d+6}_{\uparrow}}\right) + \frac{1}{2}\sum_{\downarrow}\left(\frac{Y^{d+6}_{\downarrow} - Y^d_{\downarrow}}{Y^{d+6}_{\downarrow} + Y^d_{\downarrow}}\right) = A^d_{UD}G^d_{UD} + A^d_{LR}G^d_{LR} + offset$$

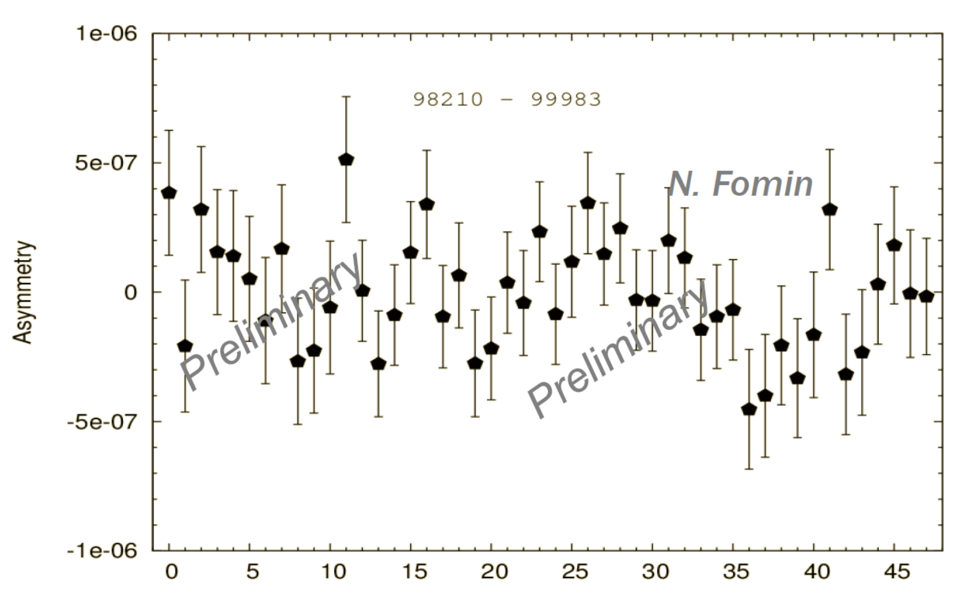
$$G^d_{UD} \propto \langle \cos\phi_d \rangle$$
$$G^d_{LR} \propto \langle \sin\phi_d \rangle$$

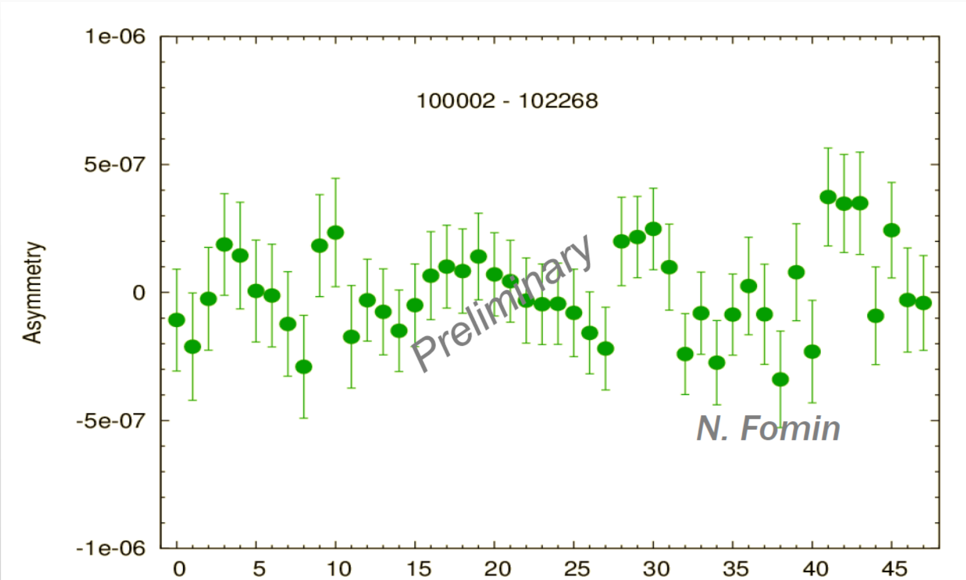


- The asymmetries are averaged over the TOF
- Measured detector asymmetries plotted against detector number
- A_{UD} and A_{LR} for all detectors are extracted from a fit to $A_{UD}G^d_{UD} + A_{LR}G^d_{LR} + c$
- Asymmetries must be corrected for backgrounds:

$$A_{PV} = \frac{A_{UD}}{P_{\vec{n}}\, S_{flip}\, C_{dep}} - F_b \frac{A_{UD,b}}{P_{\vec{n}}\, S_{flip}\, C^b_{dep}}$$

Some Results





$$A_{UD} = \left(-7.1 \pm 4.4\right) \times 10^{-8}$$

$$A_{LR} = \left(-0.91 \pm 4.3\right) \times 10^{-8}$$

Represents 17 days of data statistical uncertainty only.

Systematic errors:

Polarimetry:	$< 2\%$
Spin flip eff.:	$\sim 0.5\%$
Beam depol.:	$\sim 0.5\%$ (target dep.)
Geometry Fact.:	1%
Overlap neutrons:	0.1%
Target position:	0.03%

History and Status

- First run in 2004 at Los Alamos
- Move to ORNL and contruction / installation there 2006 – 2011
- Commissioning at ORNL 2011
- Start of production at ORNL early 2012
- Completed LH2 data production in April 2014
- Aluminum running until June 2014
- Experiment is now de-installing (my thesis experiment is finally over …)
- Analysis on-going (experiment ran for more than two years at ~70% uptime)

Thank you